Investigating Spatial Big Data for ‘Eco-routing’

My research interest is broadly in the area of routing and navigational systems, a set of ideas and technologies that transform lives by understanding the physical world, knowing and communicating relations to places in that world, and navigating through those places. Success stories of some of these systems include wide scale popularity of applications like Google maps and consumer Global Positioning System (GPS) devices. Society has immensely benefited from these kinds of systems. We’ve reached the point where a hiker in Grand Canyon, a biker in Minneapolis, and a taxi driver in Manhattan know precisely where they are, their nearby points of interest, and how to reach their destinations.

Traditionally GPS and web based navigational systems used spatial computing technologies which in turn harnessed the spatial datasets such as traditional digital road maps to suggest routes. However, with the advancement in sensor technology, spatial datasets collected by satellites, sensors, etc. exceed the capacity of commonly used spatial computing technologies. We refer to such datasets as **Spatial Big Data (SBD)**. Examples of emerging SBD datasets include traffic signal data and temporally detailed (TD) roadmaps that provide travel speeds for every minute for every road segment as well as engine measurements of fuel consumption, greenhouse gas (GHG) emissions, etc. SBD has transformative potential. For example, a 2011 McKinsey report\(^1\) estimates savings of about ``$600 billion annually by 2020'' by recommending **‘Eco-routes’ which minimize fuel consumption and GHG emissions**. Preliminary evidence for the transformative potential includes the experience of UPS, which **saves millions of gallons of fuel by simply avoiding left turns**\(^2\) and associated idling when selecting routes.

Eco-routing can significantly reduce the overall greenhouse emissions and related pollutants;

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\(^1\) New Ways to Exploit Raw Data May Bring Surge of Innovation, a Study Says, New York Times, May 13th, 2011.

given that petroleum based fuels form a major component in transportation. I propose to investigate the transformative potential of SBD for ‘Eco-routing’ by building following line of research.

**Proposed Interdisciplinary Thesis:** My doctoral thesis is focused on “Eco-routing”, computational techniques for identifying travel routes which reduce fuel consumption and GHG emissions. Although, few navigational systems have recently introduced Eco-route options, consumer experience is mixed and several interdisciplinary research questions remain unaddressed. Some of these questions include:

- **(a) Civil Engineering:** What are the impacts of traffic management systems (e.g. delays cause due to traffic signal timings)?
- **(b) Transportation Science:** What are the expected fuel savings from using TD roadmaps for Eco-routing? How much additional gain can be obtained by considering parameters like vehicle characteristics (e.g. weight and energy source) and driving behavior (gentle acceleration/braking)?
- **(c) Computer Science:** What is the computational structure of the ‘Eco-routing’ problem on temporally detailed roadmaps?

**Benefit from residence at Center for Transportation Studies (CTS):** Study of these research questions requires me to engage in cross discipline collaboration with Civil Engineers and Transportation scientists. To this end, I believe that CTS would be an appropriate place for me to pursue this interdisciplinary thesis as it is a University wide interdisciplinary hub of transportation scientists from diverse disciplines which include civil engineering, public policy and mechanical engineering. For instance, I plan to work with Prof Henry Liu, an expert in traffic lights coordination on arterial highways. He has collected signal timing dataset which may be used to assess the average wait for left and right turns. Specifically, I plan to study traffic management systems with Prof Liu (**item (a) in Proposed Interdisciplinary thesis paragraph**) and model traffic-signal timing information for routing techniques. This would help in suggesting routes which minimize idling at left turns.

I plan to address the transportation science research questions (**item (b) in Interdisciplinary

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thesis paragraph) through real world experiments using cars with engine-monitors which can record the vehicle’s location and its fuel consumption history. These experiments would help me to verify and validate my models. Specifically, I plan to assess the impact of experimental parameters such as, traffic congestion patterns from TD roadmaps, traffic signal timings, vehicle/engine characteristics (kind of fuel and engine) and human driving factors (e.g. gentle acceleration/braking) etc., on fuel efficiency of a route. Comparison metrics for these experiments would include fuel consumption and GHG emissions. In order to design these experiments, I would seek guidance and collaboration from transportation scientists with expertise in diverse disciplines such as Environmental and air-quality studies (interpreting the GHG emissions), human factors (driving factors), vehicle design and fuels, traffic engineering and management (traffic signal timings), all of which are represented at CTS. Lastly, I will regularly attend seminars conducted for CTS Scholars Program to interact with researchers at CTS to broaden my awareness into other transportation science issues impacting the environment.

**Preliminary Work:** In my preliminary work I studied the problem of fastest routes\(^4\) (routes which minimize the travel time in road map) for temporally detailed roadmaps. During this study I observed that different routes were optimal for different times (i.e. ranking of candidate routes was non-stationary). This behavior induced exorbitant computational costs for traditional routing techniques such as Dijkstra’s (used by common web based services such as Google maps). I developed a novel technique called critical-time-points\(^2\) that reduced this cost by dividing a given time interval into a set of disjoint intervals where ranking among candidate routes was stationary. Techniques developed using this insight proved to be much faster and scalable than traditional alternatives. In order to address the computational question of my thesis (*item (c) in Proposed Interdisciplinary thesis*), I propose the study notions similar to critical time points for computational scalability.